CHAPTER 4

ELEMENTS OF ORGANIC CHEMISTRY

32. INTRODUCTION

Carbon is one of the most abundant elements in our world. It is part of the molecular structure of all living organisms, the basis for our fuel and energy production, and it plays a large role in the chemistry of many of the synthetic fabrics and plastics which have become so important to our life-style. Carbon compounds also account for a vast majority of the drugs you will encounter. It is very important that you, as a health care provider, have a basic understanding of the chemistry of carbon compounds, organic chemistry, due to the roles that carbon plays.

33. CONTRAST WITH INORGANIC CHEMISTRY

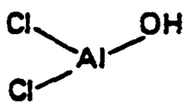
There are several general differences between the chemistries of carbon compounds and inorganic compounds which will help give you an overall view of organic chemistry (table 5).

	INORGANIC CHEMISTRY	ORGANIC CHEMISTRY
TYPE OF BONDING	Ionic	Covalent
MOLECULAR SIZE	Small	Large
WATER SOLUBILITY	Soluble	Insoluble
SOLUBILITY IN ORGANIC SOLVENTS	Insoluble	Soluble
CLASSES OF COMPOUNDS	Acid, base, or salt	Many (functional groups)
STRUCTURAL FORMULAS	Unimportant	Very important

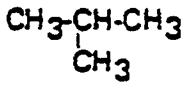
Table 5. Comparison of organic and inorganic chemistry.

34. STRUCTURAL FORMULAS

A structural formula is a chemical formula which shows which atoms are bonded to each other. For example, we might write $AlOHCl_2$ as



to show the bonds. However, in inorganic chemistry the compounds are such that there is generally only one possible way to combine the atoms. This is not the case in organic chemistry, where very often there are many possible combinations for the atoms in the compound. Consider, for example, the formula C_4H_{10}. This formula could represent either of the following compounds.

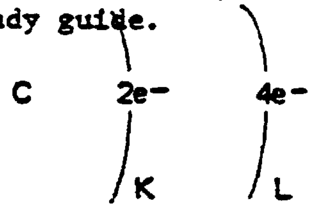


or $CH_3 \cdot CH_2 \cdot CH_2 \cdot CH_3$

These compounds have slightly different properties. As the formulas become more complex, the differences are even greater. For this reason it is often better to use a structural formula in organic chemistry rather than the simple chemical formula.

35. CARBON

Before we examine carbon compounds, we first need to examine the structure and mention some properties of the carbon atom. Carbon has an atomic number of six, meaning it has six protons, and consequently has six electrons. These electrons are distributed with two in the K shell and four in the L shell. In forming compounds, carbon would appear to gain or lose the four electrons in its outer shell. Thus, we have the +4, -4 valences you learned for carbon earlier in this study guide.

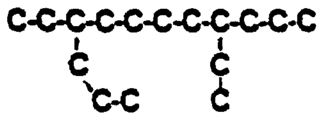


In fact, carbon does not usually exchange electrons with other elements but prefers to share four electrons to complete its L shell. This is the reason that covalent bonding is predominant in organic chemistry.

36. CARBON-CARBON BONDING

Carbon atoms have the unique ability to bond to other carbon atoms and form chains which may also have branches.

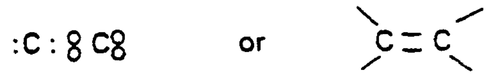
C-C-C-C-C-C-C or



This is the reason that the molecular size is so great in organic chemistry. Molecular weights in the thousands are not uncommon. There are three types of bonds which are formed between carbon atoms.

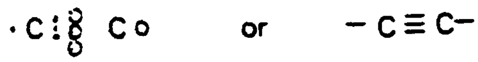
a. **Single Bonds.** A single bond is a covalent bond formed by two carbon atoms sharing two electrons. Compounds that contain *only* single bonds between carbon atoms are called *alkanes*.

b. **Double Bonds.** A double bond consists of two covalent bonds formed by two carbon atoms sharing four electrons as shown below.



Compounds that contain at least one carbon-carbon double bond are referred to as *alkenes*.

c. **Triple Bonds.** A triple bond consists of three covalent bonds formed by two carbon atoms sharing six electrons as shown below.



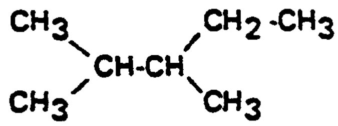
Compounds which contain at least one triple bond between carbon atoms are called *alkynes*.

37. HYDROCARBONS

The simplest organic compounds are the hydrocarbons, which are composed solely of carbon and hydrogen. Since there are only two elements involved, one might expect there would be only a few different compounds. However, carbon does bond to itself and form long chains. So there are many, many different hydrocarbons. They can be classed in two general groups, aliphatic and aromatic. These compounds are the starting point for all organic compounds.

a. **Aliphatic Hydrocarbons.** Aliphatic hydrocarbons consist of straight or branched chains of carbon atoms with the other valence electrons involved in bonds with hydrogen. Examples are:

CH_3-CH_2-CH_2-CH_2-CH_3 $\quad$ $CH_2 = CH_2$



We can subdivide aliphatic hydrocarbons into two groups based on the types of carbon-carbon bonds the compounds contain.

(1) *Saturated aliphatic hydrocarbons.* Saturated aliphatic hydrocarbons are hydrocarbons in which all of the carbon-carbon bonds are single bonds. These compounds are also referred to as alkanes, as mentioned for single bonds earlier. We often refer to the alkanes as the methane series. Methane is the simplest hydrocarbon with the formula CH_4. All other alkanes are formed by adding CH_2's to the formula (table 6). In this series the names from C_5 to C_{10} all begin with the Greek prefix for the number, e.g., penta- for five, and end in -ane from "alkane." The low-molecular-weight alkanes are gases. Alkanes are not very reactive chemically and are insoluble in water. About the most important reaction they undergo is that they burn to form carbon dioxide and water (combustion reaction). Some typical saturated compounds you might encounter are:

NAME	FORMULA	BOILING POINT (C)
Methane	CH_4	-161.5
Ethane	C_2H_6	- 88.3
Propane	C_3H_8	- 44.5
Butane	C_4H_{10}	- .5
Pentane	C_5H_{12}	+ 36.2
Hexane	C_6H_{14}	
Heptane	C_7H_{16}	
Octane	C_8H_{18}	+125.8
Nonane	C_9H_{20}	
Decane	$C_{10}H_{22}$	+174.0

Table 6. Common alkanes.

(a) *Liquid petrolatum (mineral oil).* This liquid is used as a solvent and as a laxative.

(b) *Petrolatum (petroleum jelly).* This semisolid is used as an ointment base.

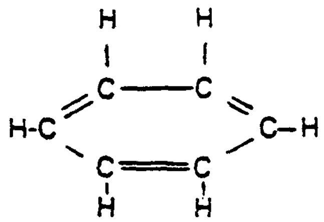
(c) *Paraffin (wax).* This solid is used in pharmacy as a stiffening agent.

(2) *Unsaturated aliphatic hydrocarbons.* The second type of aliphatic hydrocarbon is unsaturated hydrocarbons. These are hydrocarbons that contain at least one double or triple bond, i.e., they are alkenes or alkynes. An example of an alkene is ethene, the simplest alkene, which consists of two double-bonded carbon atoms and four hydrogen atoms.

$$CH_2{=}CH_2$$

Note that the name is similar to the saturated compound ethane. The -ene ending comes from the word alkene and denotes that it contains a double bond. Similarly, if there were a triple bond between the two carbon atoms the name would be ethyne with the -yne ending denoting the triple bond (from alkyne). The physical properties of alkenes and alkynes are similar to the properties of alkanes of similar molecular weights. Chemically, the word unsaturated implies that these compounds can form additional bonds. This is the case, for alkenes and alkynes are much more reactive and undergo many reactions not possible with alkanes.

b. **Aromatic Hydrocarbons.** The second major group of the hydrocarbons is the aromatic hydrocarbons, which are hydrocarbons that contain a benzene ring as part of their structure. Benzene has the formula C_6H_6 and consists of six carbon atoms in a ring with three alternating double bonds.



The benzene ring is also represented in the following manners:

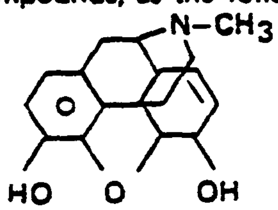
 or  or 

(1) Benzene is completely insoluble in water, it is a volatile liquid at room temperature, and it is fairly unreactive. The properties of other aromatics are reflective of benzene but vary according to the substituents added to the ring in place of one of the hydrogen atoms.

(2) The term "aromatic" has its origin in the fact that certain aromatic substances (for example: oil of bitter almonds, vanilla, and oil of wintergreen) contain the benzene ring. The possession of an odor is not characteristic, however, of all aromatic substances.

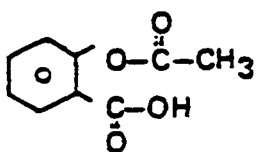
(3) Aromatic hydrocarbons are the starting point for many medicinally important compounds, as the following examples indicate.

Morphine



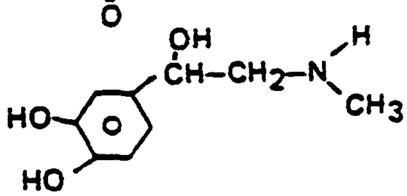
Narcotic Analgesic — For relief of severe pain.

Aspirin



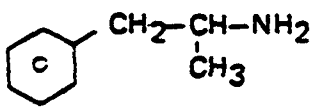
Non-Narcotic Analgesic — For relief of moderate pain.

Epinephrine



Adrenergic Drug — Used to treat shock.

Dextroamphetamine



Stimulant — For diet control, narcolepsy, and hyperkinesis.

(4) You will notice in the compounds above that they are not pure aromatic hydrocarbons because they contain elements other than carbon and hydrogen. These additional elements are the basis for the classification of substituted organic compounds and are called functional groups. The important functional groups will be considered in the following paragraphs.

38. INTRODUCTION TO FUNCTIONAL GROUPS

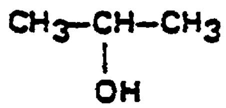
There are millions of organic compounds known to exist, and most are more complex than the simple hydrocarbons we have discussed. To facilitate the study of their reactions and properties, they are conveniently classed according to the functional groups they contain. A functional group is a group of atoms or a single atom that is substituted for a hydrogen or a hydrocarbon. These groups generally determine the types of reactions and properties of these more complex compounds. (A summary of the properties and reactions of the compounds contained in paragraphs 39 through 47 is tabulated in Table 7, pages 62-63.)

39. ALCOHOLS

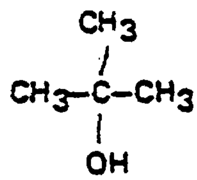
Alcohols are hydroxyl (-OH) derivatives of hydrocarbons formed by replacing a hydrogen with the hydroxyl radical and are of the general form R-OH where R represents the hydrocarbon. There are three classes of alcohols: primary, secondary, and tertiary. A *primary* alcohol is one in which the hydroxyl group is attached to a carbon atom which, in turn, is attached to not more than one other carbon atom. A *secondary* alcohol is one in which the hydroxyl group is attached to a carbon atom which, in turn, is connected to two carbon atoms. A *tertiary* alcohol is one in which the hydroxyl group is attached to a carbon atom which, in turn, is attached to three other carbon atoms.

CH_3-CH_2-OH

Primary Alcohol
Ethanol
(ethyl alcohol)

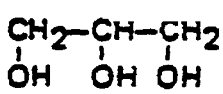


Secondary Alcohol
2-propanol
(isopropyl alcohol)



Tertiary Alcohol

Alcohols that contain two or more hydroxyl groups are referred to as *polyhydroxy* alcohols. An example you will encounter frequently in this course and on the job is glycerin, which is:



a. **Properties of Alcohols.** The low-molecular-weight alcohols are volatile liquids, and the high-molecular-weight alcohols (more than 13 carbons) are solids. The *first three* alcohols (C_1 to C_3) are completely *miscible* (mix in any proportion) with water. The water solubility decreases as the number of carbons increases, and the large-molecular-weight alcohols are insoluble in water. Alcohols have higher boiling points and melting points than alkanes with the same or similar molecular weights. For example,

	MW	MELTING POINT	BOILING POINT
$CH_3{-}CH_2{-}CH_2{-}CH_2{-}OH$	74	−90 C	118 C
$CH_3{-}CH_2{-}CH_2{-}CH_2{-}CH_3$	72	−130 C	36 C

The water solubility and the high melting and boiling points of alcohols result from their ability to form hydrogen bonds with water and to form hydrogen bonds intermolecularly (between themselves).

b. **Reactions of Alcohols.** Chemically, the alcohols can be considered to be neutral (in terms of acids and bases) even though they can act as very weak acids or bases as water does. They undergo several kinds of chemical reactions, the most important of which is oxidation. *Oxidation* in organic chemistry is defined as the elimination of hydrogen from or the addition of oxygen to a compound.

(1) The oxidation of a primary alcohol can be expressed by the following example:

$$CH_3{-}OH \xrightarrow{KMnO_4} H\overset{\overset{O}{\|}}{C}H \xrightarrow[\Delta]{O_2} H{-}\overset{\overset{O}{\|}}{C}{-}OH$$

NOTE: $\overset{H}{\diagdown}C{=}O$ and $-\overset{\overset{O}{\|}}{C}{-}OH$ are two more functional groups, indicating aldehydes and carboxylic acids, respectively.

The first step in this oxidation is the removal of two hydrogen atoms from the alcohol to form an aldehyde, and the second step is the addition of one oxygen to the aldehyde to form a carboxylic acid.

(2) Secondary alcohols undergo only the first step. For example, a three-carbon alcohol is oxidized to form $CH_3{-}\underset{\underset{O}{\|}}{C}{-}CH_3$ which is an example of a new class of compounds called ketones.

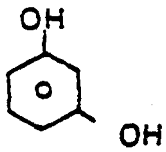
(3) Tertiary alcohols are not oxidized.

(4) One reason the oxidation reaction is important is that it is the means the body uses to eliminate the popular liquid, ethyl alcohol or ethanol ($CH_3{-}CH_2{-}OH$).

c. **Uses of Alcohols.** Alcohols are most commonly used as solvents in the pharmacy. They are also used as disinfectants and antiseptics.

40. PHENOLS

Phenols are hydroxyl derivatives of hydrocarbons formed by replacing a hydrogen on the benzene ring of an aromatic hydrocarbon with the hydroxyl radical. Phenols have the general formula Ar-OH, where Ar represents a substituted or non-substituted aromatic hydrocarbon. Thus, phenols are really just a special class of alcohols. However, they have enough unique properties that they deserve to be considered as a separate class of compounds. Below are some examples of typical phenols.

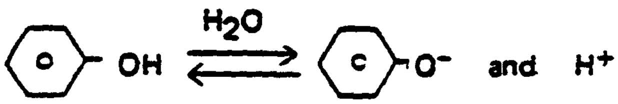


Resorcinol

Phenol (carbolic acid)

a. **Properties of Phenols.** All phenols are white solids with moderately high melting points and are soluble in water. They also have the property of being able to form eutectics with camphor, menthol, or thymol, which are solid alcohols. A eutectic is a uniform mixture formed from two compounds that melt at a temperature lower than the melting point of either of the two compounds. Thus, phenol (a solid) and camphor (a solid) form a liquid mixture at room temperature which is called a eutectic.

b. **Reactions of Phenols.** Chemically, phenols are weakly acidic compounds. The hydrogen dissociates to a small degree from the hydroxyl radical to act as an acid as shown below.



Since phenols are weak acids, they will form salts with inorganic bases. Phenols with two hydroxyl groups also undergo oxidation reactions.

c. **Uses of Phenols.** Medicinally, phenolic compounds have three uses: as keratolytics (compounds that remove hornified or scaling outer layers of skin), antipruritics (relieve itching), and disinfectants. These uses arise from the fact that phenols are very caustic to animal tissues. Precautions must therefore be taken when you are using phenols in preparations. These properties, possessed to different degrees by various phenols, depend on which other functional groups are present and the number of hydroxyl groups.

41. ETHERS

An ether can be thought of as a hydrocarbon derivative of water where the two hydrogens of water are replaced by hydrocarbon groups. Thus, ethers have the general structural formula R-O-R' where R and R' represent any two hydrocarbons, which may be alike or different. Some examples of ethers are:

CH_3-CH_2-O-CH_2-CH_3 Ø–O–CH_3 CH_2=CH–O–CH_3

a. Properties of Ethers. Ether molecules are slightly polar but cannot form hydrogen bonds with each other since they do not have a hydrogen atom attached directly to an oxygen atom. Therefore, they have about the same boiling points and melting points as alkanes of similar molecular weights.

	M.W.	Boiling Point
CH_3-CH_2-CH_2-CH_2-CH_2-CH_2-CH_3	100	98 C
CH_3-O-CH_2-CH_2-CH_2-CH_2-CH_3	102	100 C

b. Reactions of Ethers. Since ether molecules are slightly polar and have an oxygen atom in their structure, they can form hydrogen bonds with water. This property accounts for the fact that ethers are slightly soluble in water. Chemically, ethers are inert except for the oxidation reaction. Ethers are oxidized in the presence of oxygen to form peroxides which are explosive when concentrated.

c. Uses of Ethers. Medicinally, ethers are used as general anesthetics. They are also used as solvents. Many of you are involved with ordering and storing ethers.

42. AMINES

Amines result from the replacement of one or more of the hydrogen atoms of ammonia with hydrocarbons, and have the general formula R-NH_2. There are four classifications of amines: primary, secondary, tertiary, and quaternary. Primary amines result from replacing one of the hydrogens of ammonia by a hydrocarbon, as in CH_3-NH_2; secondary amines result from the replacement of two hydrogens of ammonia by two hydrocarbons, as in CH_3-NH-CH_3; and tertiary amines result from the replacement of all three hydrogens of ammonia by hydrocarbon groups. The fourth classification of amines is also sometimes encountered in drug structures. This classification is the quaternary amine which is formed by replacing the four hydrogens of the ammonium ion (NH_4^+) by hydrocarbon groups. Whenever one of the hydrocarbon groups connected to the nitrogen atom contains a benzene ring, the compound is referred to as an aromatic hydrocarbon.

a. Properties of Amines. The low-molecular-weight amines are all volatile liquids, and those having up to five carbons are soluble in water. The element nitrogen is in the same period of the periodic table as oxygen and has some similar properties—the most significant being the ability to form hydrogen bonds. The formation of hydrogen bonds between amines, and between amines and water, accounts for their higher boiling points (than alkanes) and their water solubility.

b. Reactions of Amines. Since amines are derivatives of ammonia, they are bases as defined by the Bronsted-Lowry theory. The nitrogen of the amine can accept a proton to form a substituted ammonium ion.

$$CH_3\text{-}CH_2\text{-}NH_2 + H^+ \rightarrow CH_3\text{-}CH_2\text{-}NH_3^+$$

Amines will thus react with inorganic acids to form salts. (Amines react with organic acids to form amides, a class of organic compounds discussed later in this study guide.)

$$CH_3\text{-}NH_2 + HCl \rightarrow CH_3\text{-}NH_3^+\ Cl^-$$

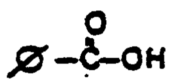
The reaction in the example above results in a hydrochloride salt of the amine and is a very important reaction in pharmacy. Many drugs contain an amine functional group, and if they contain a lot of carbon atoms, they are not very soluble in water. The salts formed from amines, however, are very soluble in water. Therefore, if we wish to use a water solution of an amine drug which is insoluble, we can make it soluble by forming the salt of the amine.

c. **Uses of Amines.** As already stated, the amine functional group is contained in many different drugs that have quite different actions in the body. Generally, these drugs are very complex, and you would never be expected to draw or know the structure for these drugs. You should, however, recognize the $\text{-}NH_2$ group of an amine and be cognizant of its basic properties.

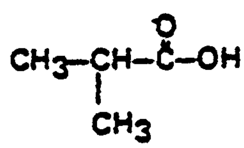
43. CARBOXYLIC ACIDS

Carboxylic acids are formed by the two-step oxidation of alcohols as stated previously and have the general structural formula $R\text{-}\overset{O}{\overset{\|}{C}}\text{-}OH$ or R-COOH. Some examples of carboxylic acids are:

Ethanoic Acid
(Acetic Acid)

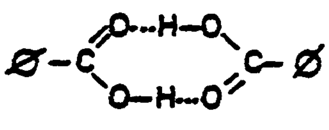


Benzoic Acid



2—Methylpropionic Acid

a. **Properties of Carboxylic Acids.** Carboxylic acids are very polar compounds due to the two oxygen atoms and can form two hydrogen bonds between themselves as shown below.



They have the highest melting points of any of the classes of compounds in table 7; a carboxylic acid has a higher melting point than a different type of organic compound with a similar molecular weight. Consequently, they are all solids under normal conditions. The compounds with four carbons or less are miscible with water; those with five carbons are slightly soluble, and those with more than five carbons are generally insoluble in water.

b. **Reactions of Carboxylic Acids.** As their name implies, carboxylic acids are the most acidic of all organic compounds but are still weak acids when compared to inorganic acids.

$$CH_3\text{-}\overset{O}{\overset{\|}{C}}\text{-}OH \rightleftharpoons CH_3\text{-}\overset{O}{\overset{\|}{C}}\text{-}O^- \; H^+$$

Carboxylic acids will form salts with inorganic bases, and as with the basic amines,. this property is often used to make insoluble organic acids soluble in water as their salt. This pair, ethanoic acid (acetic acid) and its salt sodium ethanoate (sodium acetate), is used as a buffer system.

$$CH_3\text{-}\overset{O}{\overset{\|}{C}}\text{-}OH + NaOH \longrightarrow CH_3\text{-}\overset{O}{\overset{\|}{C}}\text{-}O^- \; Na^+ + H_2O$$

Carboxylic acids undergo three other important chemical reactions: reduction, ester formation, and amide formation.

(1) Reduction in organic chemistry is the opposite of oxidation and is the addition of hydrogen to or the elimination of oxygen from a compound. In the case of carboxylic acids, the removal of oxygen first results in an aldehyde, which may be reduced further by the addition of hydrogen to form an alcohol.

(2) Ester formation, as illustrated by the reaction below, is the reaction of a carboxylic acid with an alcohol to yield a new class of compound called an ester.

$$\underset{\text{Acid}}{CH_3\text{-}COOH} + \underset{\text{Alcohol}}{CH_3\text{-}CH_2\text{-}OH} \longrightarrow \underset{\text{Ester}}{CH_3\text{—}\overset{O}{\overset{\|}{C}}\text{—}O\text{—}CH_2\text{—}CH_3} + H_2O$$

(3) Amide formation, as illustrated by the reaction below, is the reaction of a carboxylic acid with an amine to yield a new class called an amide.

$$\underset{\text{Acid}}{CH_3\text{-}COOH} + \underset{\text{Amine}}{CH_3\text{-}CH_2\text{-}NH_2} \longrightarrow \underset{\text{Amide}}{CH_3\text{—}\overset{O}{\overset{\|}{C}}\text{—}NH\text{—}CH_2\text{—}CH_3} + H_2O$$

c. **Uses of Carboxylic Acids.** Many acids, such as acetic, salicylic, and lactic, are used topically to treat local conditions. Others are used systemically. Still others, like citric acid, which is found naturally in lemons, are used to flavor syrups for administration of other drugs. They are also used in many analytical procedures in the clinical laboratory.

44. ALDEHYDES

Aldehydes result from the first oxidation of alcohols and have the general structural formula $R\text{-}\underset{O}{\underset{\|}{C}}\text{-}H$. Since aldehydes cannot form hydrogen bonds between themselves, they have lower boiling points than corresponding alcohols or acids. Again, as with the other classes of organic compounds in table 7, the lower-molecular-weight

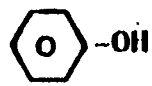
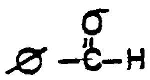
CLASS OF COMPOUNDS	ALCOHOL	PHENOL	ETHER	AMINE	CARBOXYLIC ACID	ALDEHYDE	KETONE	ESTER	AMIDE
GENERAL STRUCTURE	R–OH	Ar–OH	R–O–R	$R-NH_2$	R–C(=O)–OH	R–C(=O)–H	R–C(=O)–R	R–C(=O)–O–R	$R-C(=O)-NH_2$
	ROH	ArOH	ROR	RNH_2	RCOOH	RCOH	RCOR	RCOOR	$RCONH_2$
PRODUCT OR COMPOUND	CH_3CH_2OH		$C_2H_5OC_2H_5$	$CH_3CH_2NH_2$	$CH_3C(=O)OH$	$CH_3C(=O)H$	$CH_3C(=O)CH_3$	$CH_3C(=O)OCH_3$	$CH_3C(=O)NH_2$
NAME IN COMMON SYSTEM	ETHANOL (Ethyl Alcohol)	PHENOL	ETHYL ETHER	ETHYLAMINE	ETHANOIC ACID (Acetic Acid)	ETHANAL (Acetaldehyde)	2-PROPANONE (Methyl Ketone)	METHYL ETHANOATE (Methyl Ester)	ETHANAMIDE (Acetamide)
OTHER COMMON NAMES	GRAIN ALCOHOL	CARBOLIC ACID	DIETHYL ETHER				ACETONE DIMETHYL KETONE	DIMETHYL ESTER	
pH	NEUTRAL	SLIGHTLY ACIDIC	NEUTRAL	BASIC	ACIDIC	NEUTRAL	NEUTRAL	NEUTRAL	NEUTRAL

Table 7. Summary of properties for functional groups (continued).

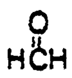
CLASS OF COMPOUNDS	ALCOHOL	PHENOL	ETHER	AMINE	CARBOXYLIC ACID	ALDEHYDE	KETONE	ESTER	AMIDE
HYDROGEN BONDING BETWEEN THEMSELVES	YES	YES	NO	YES	YES 2 – H BONDS	NO	NO	NO	YES
COMPARISON OF BOILING POINT TO CORRESPONDING ALKANE	HIGHER	HIGHER	SAME	HIGH	HIGHEST	SAME	SAME	SAME	HIGH
OXIDIZED TO	1° ALDEHYDE AND/OR ACID 2° KETONE	–	–	–	CO_2 + H_2O	ACID	ACID (VERY DIFFICULT)	–	–
REDUCED TO	–	–	–	–	ALCOHOL	ALCOHOL	2° ALCOHOL	ALCOHOL + ALCOHOL	–
HYDROLYSIS	–	–	–	–	–	–	–	ALCOHOL + ACID	ACID + AMINE

Table 7. Summary of properties for functional groups (concluded).

aldehydes (up to five carbons) are soluble in water. Aldehydes are neutral in pH and undergo both oxidation and reduction reactions. They are easily oxidized to acids and reduced to alcohols. Some aldehydes, such as vanillin and benzaldehyde, are frequently used in the pharmacy as flavoring agents.



Benzaldehyde



Ethanal
(Formaldehyde)

Others, such as formaldehyde, are often used as disinfectants.

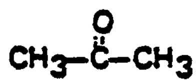
45. KETONES

Ketones result from the oxidation of a secondary alcohol and have the general structural formula R-C(=O)-R' where R and R' can be the same or different hydrocarbon groups.

a. Ketones are similar to aldehydes in their boiling points, which are lower than those of corresponding alcohols and carboxylic acids.

b. Ketones are neutral compounds, being neither acids nor bases. They undergo the process of reduction, by which they are converted to secondary alcohols.

c. The ketone functional group appears in the structure of many complex drugs, such as steroid compounds and vitamins. Simple ketones, with the exception of acetone, are seldom used. Acetone is used as a solvent and cleaning fluid.



2-propanone
(Acetone)

46. ESTERS

Esters, as previously mentioned, are formed from the reaction of a carboxylic acid with an alcohol and have the general structural formula RCOOR' or R-C(=O)OR' where R and R' can be the same or different hydrocarbon groups.

a. **Properties of Esters.** The simplest esters are liquids and have fragrant odors. An example is ethyl acetate, CH_3-CH_2-OOC-CH_3, which has the odor of pineapple. Esters cannot form hydrogen bonds between themselves; consequently, they have boiling points similar to alkanes of similar molecular weight. They can form hydrogen bonds with water; therefore, esters that contain less than five carbon atoms are soluble.

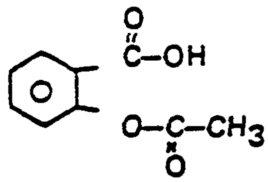
b. **Reactions of Esters.** Esters are neutral in pH and undergo two important chemical reactions, hydrolysis and reduction. Hydrolysis is the splitting of an ester with the incorporation of water to form a carboxylic acid and an alcohol.

$$R\text{-}\overset{O}{\overset{\|}{C}}\text{-}O\text{-}R' \xrightarrow{H_2O} R\text{-}\overset{O}{\overset{\|}{C}}\text{-}OH + R'\text{-}OH$$

After hydrolysis, the acid product can undergo reduction to form a second alcohol as described previously.

c. **Uses of Esters.** The ester functional group is found in many complex molecules which you will be studying in the pharmacology subcourses if you take them.

Acetylsalicylic Acid (Aspirin) - an analgesic



Nitroglycerin - a cardiac drug

$CH_2\text{—}O\text{—}NO_2$
$CH\text{—}O\text{—}NO_2$
$CH_2\text{—}O\text{—}NO_2$

47. AMIDES

Amides are formed from the reaction of a carboxylic acid with an amine or ammonia and have the general formula $R\text{—}\overset{O}{\overset{\|}{C}}\text{—}NH\text{—}R$ where R and R′ can be the same or different hydrocarbon groups.

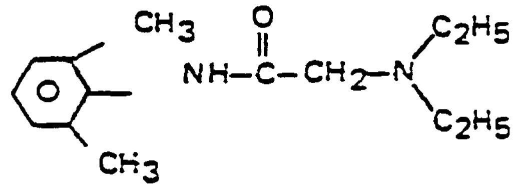
a. **Properties of Amides.** Amides, because of the hydrogen attached to the nitrogen atom, can form hydrogen bonds between themselves. They have higher boiling and melting points than corresponding alkanes. Since they can also form hydrogen bonds with water, amides containing up to five carbon atoms are soluble in water.

b. **Reactions of Amides.** Amides are neutral in pH and undergo the hydrolysis reaction. For amides, hydrolysis is the splitting of the compound with the incorporation of water to form a carboxylic acid and an amine.

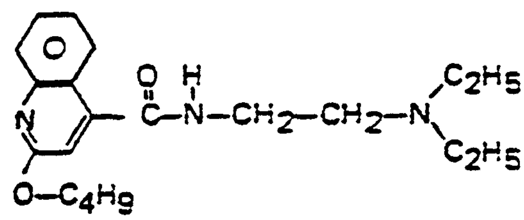
$$R\text{—}\overset{O}{\overset{\|}{C}}\text{—}NHR' \xrightarrow[H_2O]{} R\text{—}\overset{O}{\overset{\|}{C}}\text{—}OH + R'\text{—}NH_2$$

c. Uses of Amides. Some examples of drug molecules containing the amide functional group are shown below.

Lidocaine (Xylocaine[R]) = local anesthetic



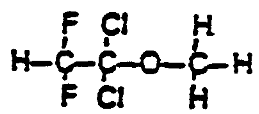
Dibucaine (Nupercaine[R]) - local anesthetic



48. HALOGENATED HYDROCARBONS

Halogenated hydrocarbons are compounds with the general formula R-X where R is any hydrocarbon group and X is a halogen (Cl, Br, F, or I). The most significant property of halogenated hydrocarbons is that as you increase the number of halogens on the compound, the flammability of the compound decreases. This property has been used to produce ethers which are nonflammable to be used as general anesthetics such as:

Methoxyflurane (Penthrane[R])



49. SUMMARY

Functional groups, when attached to various hydrocarbons, increase the reactivity and water solubility of the hydrocarbon. Carboxylic acids and phenols are the only organic acids; they are weak acids. Amines are the only significant organic bases. All functional groups that contain a hydrogen connected to a nitrogen or oxygen atom have the ability to form hydrogen bonds between themselves. All functional groups that contain a nitrogen or oxygen atom can form hydrogen bonds with water, which increase their solubility. In general, organic compounds of low molecular weight (less than five carbons) which contain functional groups, are soluble in water. Table 7 summarizes the properties and some reactions of the organic compounds we have studied.

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